Architects, Makers, and Challenges

Challenge-Based Learning and Maker Technology

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Challenge-Based Learning as a pedagogical approach exists already for about 15 years. The approach aims to train students tackle complex assignments by themselves. It is an approach however, which is not applied yet very much, at least not in our school. In this paper we show the results of applying CBL in a design computation course of the past three years. Contrary to traditional education, in CBL students have to construct their own learning path informed by their critical understanding of the challenge that they try to solve. Key aspect of the challenge is that it is provided by someone else than the teacher. In this paper we put special attention to the last year ('23-'24) where Maker technology played a key role in the challenge.

Keywords: *Challenge-Based Learning; Design computing; Maker technology*

INTRODUCTION

Challenge-Based Learning (CBL) is a pedagogical model that has emerged in Science, Technology, Engineering, and Mathematics (STEM) education (Johnson et al. 2009; Malmqvist et al 2015; Gallagher and Savage 2022). The approach was pioneered by the company Apple (Apple 2010). The developers of the approach realized that contemporary STEM education does little to prepare graduates how to work with realistic and complex tasks. In Challenge-Based Learning, teams of students work on challenges offered usually by firms, reflecting concrete, complex, and open-ended problems. Students must come up with solutions to the challenge. With this as end-goal in mind, they need to construct their own learning path, work together, identify and use resources, and so on. CBL differs from traditional frontal teaching where the educator and the school is taken as the locus of all (specialized) knowledge and students are consumers of this knowledge. CBL acknowledges that in today's world, knowledge is much more distributed beyond teaching institutes. Students need to acquire the skills how to find and apply such knowledge obtained from the internet and people outside the teaching institution.

Czech Technical University is part of a European Alliance of Technical Universities called EuroTeQ. The Alliance includes Technical University Munich, Danish Technical University, Eindhoven University of Technology, Tallinn University of Technology, Institut Polytechnique de Paris, Hautes Études Commerciales HEC Paris, IESE Business School Barcelona, and associated partners EPFL Lausanne and Technion Haifa. A key feature of education throughout the Alliance is CBL, however, CBL is still very new in our school. In the past three years, we apply CBL on two levels at our institution, including the faculty of architecture: (1) transformation of existing courses in the curriculum to the CBL format; and (2) an international special CBL project that works cross-faculty for all students. In this paper we present findings of the first, where we show the three-year period of CBL application in a Design Computation course.

Apart from the general overview of this course, we put emphasis on the latest edition in which Maker Technology played a key role in the challenge for the students.

OVERVIEW OF THE COURSE

The course in question is an introductory course in the Master level on design computation. It is an elective course awarded with 2 ECTS. In the Bachelor programme, students are taught basic skills in CAD and BIM. Except for very few design studios, students are not exposed to concepts of parametric modelling and advanced computational techniques. Thus the course has to cover a lot of ground. The format of CBL allows for a wider variety of learning paths for the students than traditional format, which was another motivation to start working in this pedagogical approach. The course fulfils two goals: (1) teach principles of design computation; and (2) hands-on experience with design computation tools. In this way, also the structure of the course is setup through theoretical lectures, and work on the challenges.

The course editions discussed in the paper are from study years '21-'22, '22-'23, and '23-'24. It must be noted that in '21-'22 the education was online due to COVID-19 pandemic measurements, and in '22-'23 partially hybrid.

Three cohorts of in total about 40 students have passed through the course. The largest number of students was in the last edition.

The topics of the theoretical classes adapted over the years to cover recent developments as well. In general, the theoretical topics included pioneers of design computing, parametric modelling, digital design process, interactive architecture, Anthropocene and post-human, and artificial intelligence.

CHALLENGE-BASED LEARNING

The core of CBL is the challenge provided to the students. In the course, we follow the structure as originally developed by Apple (2010).

Figure 1
Structure of CBL according to Apple (2010).

Students are confronted on the level of „The Challenge"; in other words, the problem or task that they have to solve. Examples of such challenges are: briquette press made from refuse wood; safe water provision in Timor-Leste; alternatives to firewood for fuel in Uganda; covering system for orchards that reduce use of pesticides while producing solar energy; and waste management in rural India, and so on (Malmqvist et al 2015).

Students need to rephrase the challenge from the concrete problem at hand to a more so-called "Essential Question". In other words, they have to see beyond the details and focus on main principles and issues in the challenge. In even more abstract terms, the essential question then translated into a "Big Idea" which is the overarching theme of the challenge. Such big ideas are for example, sustainability, social justice, waste reduction, and so on.

To solve the challenge, students need to develop three resources. The "Guiding Questions" are follow-up questions that specify precisely what things need to be answered to solve the challenge. Through this partitioning of the challenge, students will have to formulate and plan their "Guiding Activities"; in other words, their own schedule how to solve the challenge. A major skill concerns self-identifying where students lack skills and knowledge. These need to be complemented through the "Guiding Resources." These three resources form the self-constructed learning path of the students.

The solution to the challenge is produced in the "Solution: Implementation" phase. An important counter-part to this is the "Evaluation/Assessment" part where students self-report on their learning path.

Students are presented with this structure. It provides them also with the basic setup of their final report for their solution of the challenge.

The challenges

The challenge is provided by the so-called challenge owner. Ideally, the challenge-owner should be someone not directly affiliated by the course teacher (to assure disconnection from the school context and to give the challenge more realistic credibility).

Challenge owners in the editions of the course were: architect René van Zuuk, architect Gijs Joossen, and Maker Institute director Leyla Yunis (co-author of this paper). The challenge owners are selected on their expertise using design computational skills, as well as their availability throughout the course.

At the start of the course, each challenge presentation is preceded by a lecture of the challenge owner, so that the student gets a more comprehensive picture of the context that informs the challenge.

Challenge '21-'22

The challenge was provided by architect René van Zuuk. The challenge was formulated as follows: "Buildings are made of rectangular, straight, and flat elements – resulting in rectangular buildings. Making organic shapes is expensive and results in a lot of waste. Your challenge is to come up with a system that uses regular elements but with which you can make an organic pavilion. Your system should produce less than 3% waste. The pavilion should have a footprint of at least 100m2. You cannot use bricks or 3D printing."

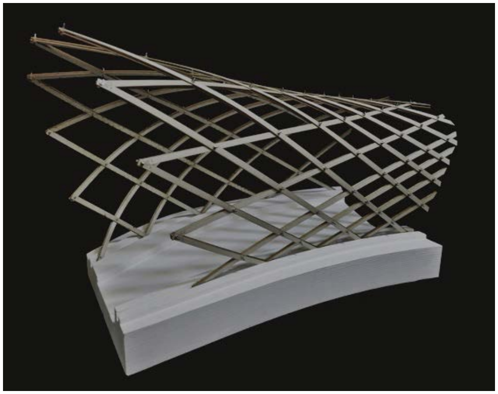

Figure 2
Work by Jan Stepanek and Jan Durrer ('21-'22).

The emphasis in the challenge on less than 3% waste required the students to put more than regular attention to the realisation part of the design. This is very often a neglected part in this type of projects, so we perceived this as very beneficial. The challenge promoted the use of parametric design to generate model variations and provide the necessary data to compute in a performance-based approach the amount of waste produced for each design. Most students used Rhinoceros 3D and Grasshopper to tackle the challenge.

Challenge '22-'23

The challenge was provided by architect Gijs Joossen. The challenge was formulated as follows: "Some buildings have a distinct shape that is driven by their function. But as each project is unique in its requirements and context, we cannot create a standard building. We can however capture the steps you as an architect take to tailor a design to the specific needs of the project and location. These steps form the base of a parametric building typology. Your challenge is to come up with a design concept for a spectator pavilion that can adapt to different conditions. These conditions can be internal (different program of requirements) or external (different location). With your parametric model you configure three different solutions that share the same system, look & feel. The parametric model has both bottom-up and top-down control as to allow interaction between intuitive form finding and rule-based generative design."

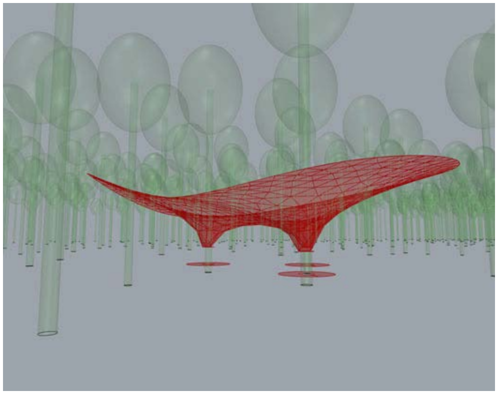

Figure 3
Work by Pierre Ballif, Suhyoon Lee, and Joosep Viik ('22-'23).

For many students, the requirement that the design should adapt to program or site proved challenging. This aspect moved them out of their comfort zone of fixed solutions to start thinking about systems rather than one-off solutions.

There was a specific focus from the start on parametric modelling. Similar as the year before, students mostly used Rhinoceros 3D and Grasshopper to develop their solutions.

Challenge '23'-'24

The challenge was provided by Maker Institute director Leyla Yunis. The challenge was formulated as follows: "Maker technology brings industry-grade precise fabrication into the hands of everyone. This allows a democratization of production tools that until now were limited to production capabilities of companies, requiring large investments and expertise. Your challenge is to apply Maker technology to create an architectural product. Use design computational strategies to create a family of parametric solutions rather than one-off designs".

Figure 4
Work by Maks Pawlak ('23-'24).

Thanks to the collaboration with the Maker Institute as challenge owner, we could install a small Maker lab in the design studio which was accessible for students following the course, as well for students enrolled in the design studio.
The requirement to apply Maker technology in the challenge turned the students to the production of tangible objects. Thus there was an early shift from pure parametric design as only virtual exploration to the materialization part of the challenge solution.

Structure of the process

The main strategy of CBL learning is built on two aspects. The first is the framework in Figure 1 above. This structure identifies levels of inquiry for the students how to investigate the challenge. The second is a three phase process that consists of the actions "Engage," "Investigate," and "Act."

The framework helps students guide their process throughout the semester. Central to CBL is the challenge itself. By reflecting on broader issues (essential question and big idea) the students put context to the challenge. Answering these issues fall under the actions of "Engage." With Engage the students become aware of the content of the challenge and activate their learning process.

To solve the challenge, students need knowledge and skills pertinent to the challenge and its solution. This is where the self-learning path of the students starts. They need to identify their knowledge and skill gap and find how to fill those gaps. This is answered in detail through the aspects guiding questions, guiding activities, and guiding resources – in other words, the "Investigate" step. This step gives students the tools to tackle the challenge.

The "Act" phase then proceeds as students come up with solutions to the challenges. Solution is always complemented with Evaluation and assessment, so that the students determine the degree of success of their work.

The 'Maker' challenge in more detail

The third challenge extended beyond Design Computing concepts by incorporating maker technology into the fabrication process. Students engaged in a combination of theoretical instruction and hands-on activities, which helped them understand both computational design principles and their practical application through fabrication technologies. The class was conducted every second week, with six sessions that either focused on theoretical discussions or integrated maker activities and technologies. Students were required to develop a computational design or thinking experiment and then bring their concept to life using maker tools. Sample technologies were provided to guide students in their projects. Decision-making for each sample was informed by collected data, which was analysed through students' project work and reflections. Throughout the course, students were also required to create an initial presentation and, at the end, provide feedback on their experiences, ensuring an iterative improvement process for future iterations of the studio.

STUDENT WORK CASE

The challenge in the framework of Maker technology added a lot of value that the students did not only focus on the digital aspects but also on the production of a real object using Maker technology. Since the 'language' for using tools like lasercutter and 3D printer is digital anyway, there was a strong synergy between working computationally and physically.

Due to scheduling issues that happened during the semester, from the cohort of 20 students, only 7 students handed in final work. Although students appreciated the content and application, they also perceived the required workload to be above the assigned 2 ECTS of the course.

The works handed in by the students were focused on the following solutions: (1) 3D printing of vermicomposting pot; (2) reflecting screen for home-grown produce; (3) moveable urban furniture; (4) customizable indoor flower planter; (5) configurable insect-hotel; (6) 3D printing and lasercutter for restoring of destroyed windows in Ukraine; and (7) DIY home acoustic panels. The latter will be described in more detail here.

DIY home acoustic panels

This work was done by student Maks Pawlak. In the Engage phase, Maks Pawlak decided to look at acoustic panels for home situation. He noted an opportunity for Maker technology to produce such panels in a Do-It-Yourself (DIY) manner rather than turning to regular produced acoustic panels that are quite expensive for private use. At the same time, as Essential Question and the Big Idea from the Apple framework, he wanted to address the problem of textile waste and paper waste, and incorporate this waste into the solution of his project. The target location for the acoustic panels are home and smaller workplaces where the main function of the panel is reverb reduction. To support this intuition, he did some initial research on acoustic panels to check the viability of the hypothesis.

In the Investigate phase, Max Pawlak researched both the material track concerning solutions with proper acoustic parameters, and parametric design computing techniques to create variations of panels with different dimensions and shapes.

In the material track, various mixes of paper and textile shreds were created to make bodies of these materials that then could be further tested in terms of sound diffusion and absorption properties. To investigate expected properties, Maks Pawlak used Pachyderm machine learning program to predict possible outcomes of the various mixes.

Figure 5:
Material research of paper shred mix. Work by Maks Pawlak ('23-'24).

In parallel, in the computing track, Maks Pawlak investigated several mould shapes in which the researched materials could be placed to create the panels.

Figure 6:
Mould variant and material test. Work by Maks Pawlak ('23-'24).

The Act phase was done by creating prototypes of the various solutions that were found to be most promising for future work. In this phase, the Maker technology was put to the test to come up with acoustic panels that had sufficient strength and stiffness to take the internal load of the acoustic material and also to make them modular and stackable for interior space use. This stage took various iterations and tests.

Figure 7:
Final framework prototype for acoustic panel (lasercutting). Work by Maks Pawlak ('23-'24).

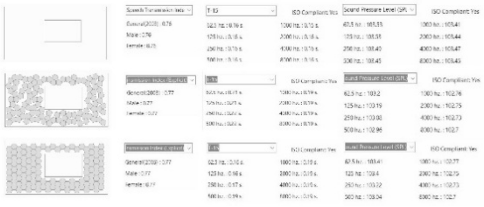

Figure 8: Acoustic testing of panel configurations. Work by Maks Pawlak ('23-'24).

This prototype was then tested in various stackable configurations on a wall for its acoustic properties.

From the acoustic tests it was shown that the most absorption would occur in mid- and high-range frequencies.

In the final report, Maks Pawlak documented the whole process, and referred to the Apple framework to identify the learned skills in the project.

DISCUSSION

It must be said that not only the students learned, but also the teachers. CBL requires more emphasis on the management of the meta-level of learning, which is dramatically different from tradition outcome-based education. In this paper we outline the lessons learned and show future developments for this approach.

From our experiences it is clear that CBL prepares students for a practice that is complex, open-ended, and requires team work. However, it requires special care in the context and structuring. Particular attention should be taken that it is does not result in a mini-design studio assignment because this is the form that they are most used to in the school context.

The Apple framework, combined with the stages Engage, Investigate, and Act give enough handles for the students to self-structure their learning process. It has become clear as well though, that additional attention should be spent throughout the course to guide students in this process. Especially in an educational context where CBL is new, students lack the mind-set that makes them autonomous learners. The teacher in this respect has a strong role as coach to make this process clear for the students, and to facilitate them on the way. A careful balance must be struck that this coaching does not end up as a traditional step-by-step instruction which the students should follow blindly. As stated earlier, this is where we as teachers are learning along the way as well.

Challenge-Based Learning is supposed to foster a self-aware process by the students of their learning path. From the partner schools in the EuroTeQ Alliance we see that broad adoption of CBL gives students this background. In our case, however, such a culture of critical self-reflection is lacking. Students are highly end-result oriented without due consideration of their process. Thus they tend to jump to conclusions without covering all related aspects to their challenge.

From the teacher side, this provides the challenge how to counter these tendencies without putting the learners into a fixed and pre-defined stepwise approach. Such a strict way goes against the main learning target of CBL that students have to figure it out by themselves. A satisfactory path has not been discovered yet – this is still a long way to develop from the side of the teachers.

CONCLUSIONS

It is fair to say that CBL bears much resemblance to design studio work. So even if the official pedagogy of CBL has not seen much application in architectural education, we do have much related experience – in fact, studio teaching is one of the cornerstones of architectural education. However, there are also differences that one must keep in mind to make CBL effective.

A very practical aspect is the amount of credits awarded to the course in comparison to studio work. The demonstrated work by student Maks Pawlak clearly goes above and beyond what could be expected in the course. This is a point for continued attention to make the work-load bearable while at the same time allowing sufficient depth in the process.

The evaluation of design studio work is very strongly focussed on the quality of the end result (the final design) with less emphasis on the process (which arguably should be evaluated in studios as well). In CBL, self-structuring the process, and developing the required skill set is much more important than the end result itself (but that arguably also plays a role in final evaluation).

We found that in the last iteration of the course, the integration of Maker technology in the challenge worked very productive. In the current edition of the course ('24-'25) the challenge is on the potential application of 3D printing technology for architectural products. This course is still ongoing, so results cannot be reported yet.

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REFERENCES
Apple (2010) *Challenge-Based Learning. A Classroom Guide* [online]. Available at: https://www.apple.com/br/education/docs/CBL_Classroom_Guide_Jan_2011.pdf (Accessed: 20 March 2025).

Gallagher, S.E. and Savage, T. (2022) 'Challenge Based Learning: Recommendations for the Future of Higher Education' in Vilalta-Perdomo, E., Membrillo-Hernandez, J., Michel-Villareal, R., Lakshmi, G. and Martinez-Acosta, M. (eds). *The Emerald Handbook of Challenge Based Learning*. Leeds: Emerald Publishing Limited.

Johnson, L.F., Smith, R.S., Smythe, J.T. and Varon, R.K. (2009). 'Challenge-Based Learning: An approach for our time'. Austin, Texas: The New Media Consortium. ISBN 978-0-9765087-4-8. Accessed via ERIC Institute of Education Sciences: https://eric.ed.gov/?id=ED505102 (accessed 18 June 2025).

Malmqvist J., Radberg KK and Lundqvist U (2015) 'Comparative analysis of Challenge-Based Learning experiences' in Wu, X. and Gu, P. (eds.) *Proceedings of the 11th International CDIO Conference,* Chengdu, Sichuan, P.R. China: Chengdu University of Information Technology.